Assessing sleep regularity: theoretical and practical implications of available metrics

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Background

Irregular sleep, a proxy for circadian disruption in the field, has been associated with adverse health effects[1]. Sleep regularity has been assessed by focusing on average sleep-wake patterns, using metrics such as standard deviation (**StDev**), Interdaily Stability (**IS**)[2], and Social Jet Lag (**SJL**)[3]. Novel metrics have been proposed to instead capture variability between consecutive days: the Composite Phase Deviation (**CPD**)[4] and the Sleep Regularity Index (**SRI**)[5]. We systematically compared these metrics across different sources of daily variability (e.g., naps, awakenings), number of days and participants.

Methods

Sleep-wake patterns were synthetically generated over 2-28 days with weekday-weekend differences. Daily sleep variability was introduced by randomly drawing daily midsleeps and/or sleep durations from a normal distribution with standard deviation ranging from 0-120 min. Average estimates and 95% confidence intervals (CIs) were calculated for: 'scrambling' the order of sleeps; fragmented sleep: naps and wake after sleep onset (WASO); "all-nighters" (nights with no sleep); and different study lengths (2-28d). Sample sizes were determined for two-group comparisons (i.e. regular *vs.* irregular sleepers) using Welch's t-test.

Results

1) Metrics measure on different time scales: global *vs.* circadian metrics.

	Deviation	Overlap
Global	StDev	IS
Circadian	CPD	SRI

'Scrambling'

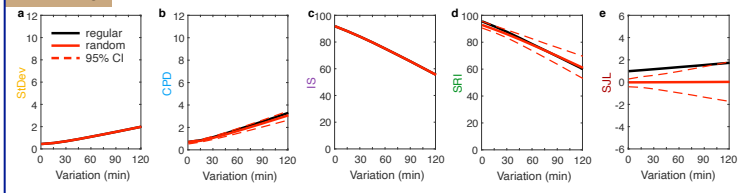


Figure 2. Global *vs.* circadian metrics. When sleep episodes were randomly re-ordered, StDev (a) and IS (c) remained identical, whereas CPD (b) and SRI (d) were affected, showing that the metrics measure on different time scales: StDev/IS measure on a ***global scale*** returning the same values irrespective of day-to-day changes, whereas CPD/SRI measure on a ***circadian scale*** capturing changes between consecutive days. Scrambling removed the weekday-weekend difference and thus SJL (e) equaled zero.

2) Metrics integrate different amounts of data: deviation *vs.* overlap metrics.

	Deviation	Overlap
Global	StDev	IS
Circadian	CPD	SRI

Increasing daily variability

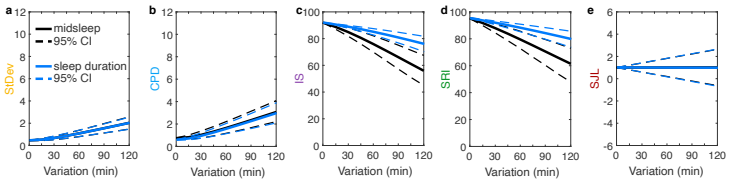
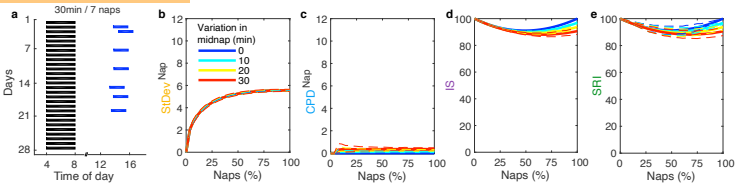


Figure 3. Deviation *vs.* overlap metrics. StDev (a) and CPD (b) use values derived from sleep-wake patterns to quantify the deviation of daily sleep from reference sleep (**deviation metrics**), whereas IS (c) and SRI (d) use the entirety of sleep-wake patterns to quantify the overlap between daily patterns and the average pattern (IS), respectively, between adjacent patterns (SRI) (**overlap metrics**). SJL (e) is a measure of weekly but not daily sleep regularity (values do not change with increasing daily variability).
i) Overlap (but not deviation) metrics' range is wider for daily variability in midsleep *vs.* duration.
ii) Overlap (but not deviation) metrics integrate variability from multiple sources (midsleep AND duration).

3) Overlap, but not deviation, metrics assess fragmented sleep.

Fragmented sleep: naps



Fragmented sleep: WASO

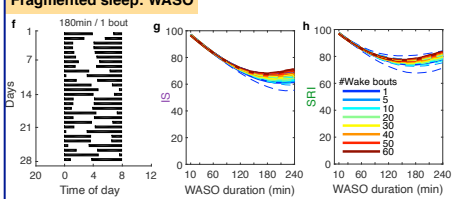


Figure 4. Fragmented sleep: naps (a), WASO (f). Overlap metrics IS/SRI accurately reflected fragmented sleep (d-h), while deviation metrics either captured only one dimension, e.g., № of naps (StDev, b) *vs.* variability in nap timing (CPD, c), or could not assess fragmented sleep at all (WASO). For WASO, total duration (not № of wake bouts) determined IS/SRI 'irregularity'.

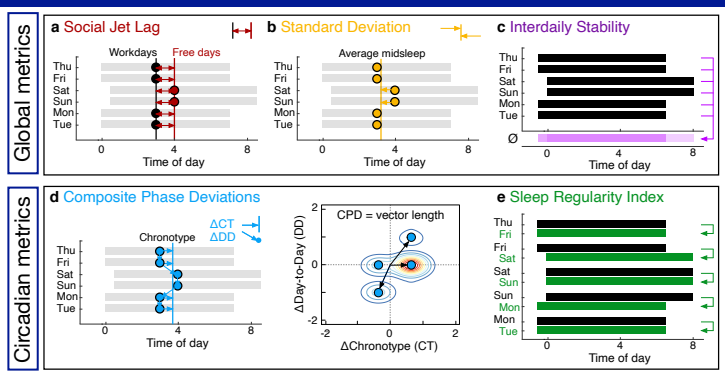


Figure 1. Sleep regularity metrics. Global metrics SJL (a), StDev (b), and IS (c) quantify overall sleep variability, comparing each day to the average, whereas circadian metrics CPD (d) and SRI (e) quantify variability between days, comparing each day to the next.

4) IS assesses stability, not regularity, of sleep-wake rhythms.

'All-nighters'

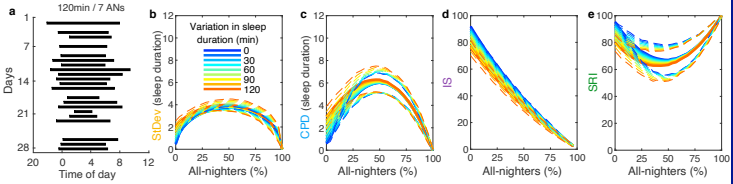


Figure 5. Stability *vs.* regularity. With increasingly absent sleep (a), values of StDev (b), CPD (c), and SRI (e) returned to a 'perfectly regular' score for constant wakefulness, whereas IS yielded monotonically lower ('less regular') values, suggesting that IS does not assess the regularity of a sleep-wake pattern without consideration of its 'stability': for a *sleep-wake* rhythm to be regular, both sleep and wakefulness need to be present.

5) Global metrics require relatively many days for an accurate estimate, whereas circadian metrics require larger samples.

Study length

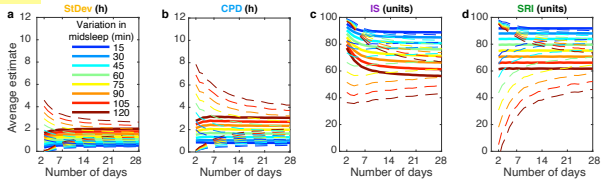


Figure 6. Number of days. Global metrics were less stable over the first 7 days than circadian metrics: StDev/IS changed up to 33%/39% (a,c) *vs.* CPD/SRI up to 9%/1% (b,d) (compared with mean at 28d). While 95% CIs narrowed with more days for all metrics, CPD/SRI had generally wider CIs than StDev/IS, due to circadian metrics measuring on a day-to-day timescale.

Sample size

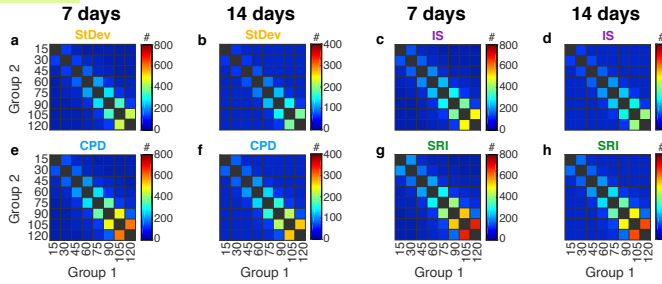


Figure 7. Number of participants. Due to their wider CIs, CPD/SRI (e-h) required on average 20% larger sample sizes than StDev/IS (a-d) but that number decreased with more days (e.g.,12% for 28-d patterns). Sample sizes were not increased for CPD/SRI when comparing groups of very different sleep regularity (dark-blue cells, i.e., regular *vs.* irregular sleepers).

Wrap-up

The metrics measure different aspects of sleep regularity and should be seen as complementary rather than competitive. Global metrics require relatively many days for an accurate estimate, whereas circadian metrics require larger samples. Selecting a metric will need to balance study length and sample size. Studies should include more than one metric to capture different aspects of sleep regularity and examine its potential as a proxy for circadian disruption in the field.

[1]Bei B, et al (2012). Beyond the mean: A systematic review on the correlates of daily intraindividual variability of sleep/wake patterns. Sleep Med Rev;28:108-124 [2]Witting W, et al (2012). Alterations in the circadian rest-activity rhythm in aging and Alzheimer's disease. Biol Psychiatry;27(6):563-572 [3]Roenneberg T, et al (2012). Social Jetlag and Obesity. Curr Biol;22(10):939-943 [4]Fischer D, et al (2012). A novel method to visualise and quantify circadian misalignment. Sci Rep;6:38601 [5]Phillips AJK, et al (2012). Irregular sleep/wake patterns are associated with poorer academic performance and delayed circadian and sleep/wake timing. Sci Rep;7:3216